4. On 10 nights when the surface of the ground was frozen the air temperature varied from 3.2° to 0.3° (C.) lower than the surface-soil temperature, with an average of 2.7° (C.) cooler. On 28 nights when the surface did not freeze the air temperature minimum averaged 0.4° (C.) higher than the surface-soil temperature, the variation being from 1° higher to 1° (C.) lower. It follows, therefore, that when the surface of the ground does not freeze the air minimum over open soil follows the surface-soil minimum very closely.

In a later paper in the same publication (pp. 56–79) Dr. Franklin discusses soil temperatures further under the head, "The Effect of Weather Changes on Soil Temperature." The following are brief quotations from this article:

In comparison with the variation of surface temperature, the regular pulsations of temperature underground follow well-known laws for amplitude and retardation according to depth; but in these regular pulsations there are minor fluctuations which occur either day by day or at irregular intervals, according to the weather and the state of the surface soil.

Of these minor fluctuations the most important are due to the percolation of rain, the movements of soil air and moisture, the presence of a dry surface mulch, the prevalence of strong winds of low relative humidity, or the occurrence of frost and snow. * * *

Rain is a great equalizer of temperature between the surface and underground—in fact, it is probable that the first rise of temperature underground from the low level of winter is due to warm spring rains. * * *

Snow is an extremely bad conductor, and as little as 4 inches of snow provides a complete protection for the surface from very large variation of temperature above the snow surface. * * *

It is obvious that so long as the air temperature was above −15° C. thawing must have been going on constantly at the bottom of the snow layer, this thawing being the more rapid the more the air temperature rose.

*The coming of spring.*—Spring, considered as the beginning of the period of active growth of crops, depends in the main on the soil temperature at the depth at which these crops grow. At first sight it would appear a simple matter—with the meteorological data for any year before us—to say whether that year had enjoyed an early or late spring; but when we study the phenological returns for the last 30 years the question assumes a more complex appearance.

If we plot the deviations from the normal of the date of first flowering of any plant against the corresponding deviations from normal for some chosen preceding period of the values of the mean, maximum, minimum, or soil temperatures, we do not find the closely corresponding results that we may have expected. As, however, mean values cover a multitude of variations, this is not to be wondered at, and it is doubtful if any good result can be obtained from monthly mean values at all. For let us consider two extreme months—

(1) With a very small range of temperature and a mean equal to the average.

(2) With a spell of frost for, say, 15 days, and very warm weather for 15 days, and a mean above the average.

Now, if the growing temperature for the plant considered was below the mean for the month, No. 1 would give nearly 30 growing days, and the plant would appear in flower earlier than in No. 2, which gives only 15 growing days, although the mean temperature of No. 2 is higher than of No. 1.

Thus not only the growing temperature of the plant, but the daily values that make up the mean, have to be known before we can make any rule for the behavior of the plant under the given conditions, and the date when the minimum soil temperature at from 4 to 6 inches depth passes the growing temperature of the proposed crop is the real question that concerns the cultivator.

If we take 5.5° C. as the average growing temperature of most crops, it is of interest to note how weather changes help forward or retard the arrival of this temperature in the soil at 4 inches depth.

In March and April, 1919, there was a succession of spells of very different weather, which showed by their influence on the 4-inch depth temperature that it is the overcast weather, with bright intervals and overcast nights, that most rapidly increases the temperature underground, and not, as might be expected, the bright, sunny weather with clear sky and low relative humidity.

These figures (omitted) emphasize the importance of the effect of frost and clear nights on underground temperatures; in fact, we may say that the soil temperature for any period in winter or spring is mainly dependent on the number of frosts which occur while the ground is open without deep-lying snow during that period. Frosts that occur when several inches of snow is lying have, as we have already seen, little effect on soil temperature, owing to the great protection given by the snow. * * *

*Conclusions.*—1. The values of $\frac{R_4}{R_0}$ have a wide range of variation, from 0.19 in very dry soil to 0.85 during heavy rain; the most common value is about 0.40. The monthly mean values showed a decided connection between $\frac{R_4}{R_0}$ and the frequency of rainfall; in fact, percolation of rain seems to be the dominating factor in deciding the value of $\frac{R_4}{R_0}$. This is also borne out by the different values of $\frac{R_4}{R_0}$ in various soils according to their behavior with regard to water; in sand the values change with mercurial rapidity, due to the easy percolation of rain and subsequent rapid drying, while in clay they change but sluggishly, since clay takes up and parts with water with difficulty.

2. In view of the fact that the values of $\frac{R_4}{R_0}$, and therefore the values of the diffusivity of the soul, are so dependent on the percolation of rain, it is possible that the values commonly given for the diffusivity of the surface layers of the earth need revision.

3. Underground temperatures are also considerably affected by—

(*a*) Strong winds of low relative humidity.

(*b*) The frequency and intensity of frost when the soil has no snow covering.

(*c*) The depth of snow.

(*d*) Weather changes of long period.

4. The date of flowering of Coltsfoot appears to bear little relation to the monthly mean values of temperature, but is closely related to the number of frosts on open soil not covered with deep snow. It is possible that good results would be obtained by comparing the phenological returns of the last thirty years with the accumulated temperature underground above the growing temperature for each plant considered.

—*J. Warren Smith.*

## EFFECT OF SOIL ON FROST DAMAGE.

In a letter to *Science* (Mar. 28, 1919, pp. 310–311), Mr. T. G. Dabney describes the effect of the onslaught of a killing frost upon vegetation growing upon soils of different character. It was observed that cotton growing in the river silt near the old river bank of the Mississippi was not damaged, but that that growing back from the river bank in the heavy clay, known locally as "buckshot," was completely killed. The explanation offered was that the radiation from the silty soil during the cold night was sufficient to protect the plants, while the clay did not possess this property. The cold night was not preceded by other cold ones but came suddenly when the soil was warm. The country in the vicinity was very level.—*C. L. M.*

## PREDICTING MINIMUM TEMPERATURES FROM THE PREVIOUS AFTERNOON WET-BULB TEMPERATURE.

In Geografiska Annaler, January, 1920 (pp. 20–32), Anders Ångström, of Upsala, Sweden, under the title "Studies of the Frost Problem, I," shows that very close minimum temperature forecasts can be made on comparatively clear nights by subtracting a constant from the wet-bulb temperature.

The constant was smallest and the percentage of accuracy highest when the observation of the wet-bulb temperature was made at about sunset, but fairly close predictions resulted from observation at other afternoon hours, even as early as 1 p. m. The constant varies with different hours and different months; Dr. Ångström found it to be greatest at 3 p. m.

The discussion shows "that the minimum temperature may be obtained through subtracting a constant value from the temperature of the wet bulb at sunset multiplied by a constant factor and diminished by the temperature of the dry-bulb thermometer multiplied by a certain factor." He found, however, that the factor which ought to be applied to the temperature of the wet thermometer is very nearly equal to 1 and further that the temperature of the dry thermometer enters with a factor that is not large. This leaves the equation $T_{min.} = t_1 - k$, or the wet-bulb temperature minus a constant (k) as indicated above.

The author says in closing, "* * * : Still there are some important factors left, which in a high degree influence the cooling of the ground and which need to be more thoroughly considered. I allude to the conductivity, heat capacity, and temperature gradient of the ground, which all are important causes of the local variations in minimum temperatures found at places situated near to one another. ' reat progress in our preditions of temperature changes of the ground will never be possible until these last-named problems are seriously attacked."

Dr. Franklin's investigations reviewed (above or on pp. 639–640) cover the points referred to by Dr. Ångström.—*J. Warren Smith.*

## PROBLEMS ON THE RELATION BETWEEN WEATHER AND CROPS.

LLOYD D. VAUGHAN.

[Tiffin, Ohio, Nov. 24, 1920.]

For any crop of grain, fruit, or vegetables to come up to what is known to be its maximum yield, it must have whatever is correct in the way of soil conditions as regards fertility, drainage, etc., the proper care in planting and cultivation, and be favored by the kind of weather conditions which may happen to be suited to its requirements. The weather is by far the most variable and uncertain of the three and the study of its relation to crop growth presents a multitude of problems, the complete solution of which can not fail to be of considerable benefit to practical agriculture.

By the solution of these problems the relation between the weather and crops can be established on a quantitative basis, so that we may know the exact reason for any particular seasonal result for a certain crop and understand the connection between the coincident numerical values of crop growth or yield and weather conditions.

The following notes and list of problems will show that a great many observations and experiments of a special nature are required in this work if the results are to be of any real or permanent value. It would be advisable for this investigation to cover each locality where any of these conditions are different from those of another for it to include as many of these separate localities as possible.

1. *Temperature.*—(*a*) Observation of the daily range of temperature, or its variation in value during the full period of 24 hours. Data on the average daily temperature are required for this purpose rather than the instantaneous values noted but two or three times at certain hours during the day.

(*b*) Surface temperatures of the soil under variant conditions.

(*c*) Difference between soil and air temperatures.

(*d*) The amount of sunlight and radiation received and the presence of haze or cloudiness.

2. *Humidity.*—(*a*) Humidity, its relation to other weather factors and their combined influence on plant growth.

(*b*) The study of the sequence of changes in daily temperature, himidity, etc., from which predictions for minimum temperatures or frost conditions can be made.

3. *Rainfall.*—(*a*) Duration, or the amount falling within a certain time. This study is important in order to determine the effect of any quantity of rain on plant growth. It is very unlikely that 1 inch of rainfall in a period of one hour would be of as much benefit to a crop as would the same amount distributed over a three- to six-hour period.

In other words, the element of time as well as quantity should be taken into account and a record kept of this relation, so that by this or other means it may be possible to compare the total hours and inches of rainfall with the growth or yield of any crops.

(*b*) It is also important that a special note should be made of the time or part of the day when the precipitation occurs, and also of the soil conditions, temperature, sunshine or cloudiness, etc., immediately preceding, and for several hours following, any appreciable rainfall during the growing season.

(*c*) Temperature of catch.

(*d*) Evaporation rates, etc.

(*e*) Difference between soil and air moisture.

(*f*) The absorption of rainfall by soils and relative effect on plant growth.

4. *Effect of low temperatures on wheat and clover.*—There are three principal causes of the winter killing of these crops: (1) Smothering under an ice sheet, water, or packed and frozen snow; (2) heaving out by alternate freezing and thawing; (3) freezing by long-continued cold while having no protection.

Wheat seems to be able to withstand cold to temperatures possibly 10 or more degrees below freezing, but when these temperatures remain this low for any great length of time the plants, especially those near a crack in the soil, or which have their crown and roots exposed by the action of the wind and previous thawing, are likely to be frozen unless protected in some way.

A large total of snowfall during the dormant stage does not furnish a very reliable condition on which to depend as being the reason for the favorable outcome of this crop through the winter months.

The number of days showing the presence of snow enough to cover the plants completely may be a better indication, but as is sometimes the case the wheat may be well covered with snow through the major portion of the winter, when along toward spring there are a few days of thawing followed by a week or two of very cold weather, while the ground is nearly bare, which will discount the advantage gained through being protected all winter. The important point is that the ground should be covered with snow during the time that any conditions exist which may have an unfavorable effect on the winter survival of wheat, clover, and similar crops.

The kind of soil, the amount of moisture and organic matter contained therein, surface and under drainage, and the fall growth of these plants also have considerable to do with their survival through the winter season.

Data are needed in regard to the most favorable or unfavorable winter conditions for wheat, clover, various fruits, etc., as to the different ways in which they may be affected by the weather in combination with various modifications of the other factors named above. Also